

The Optical-Field and Inner-Shell Ionization Schemes for X-Ray Lasing

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Abstract

We review approaches to x-ray lasing using ultrashort pulse (USP) driving lasers where ionization of the lasant is not via collisional ionization. In one approach, the large electric field associated with the USP laser ionizes a column of plasma along the driving laser axis. If linear polarization is used, the field-ionized electrons have relatively low energy and rapid recombination immediately follows. X-ray lasing down to the ground state of the ion is possible because of the complete emptying of the state by field ionization.¹ Following demonstration of small gain-length lasing in H-like Li at 135 Å², there were similar observations at other laboratories.^{3,4} However, obtaining a large gain-length product (gL) requires low temperatures following ionization and a reasonable length of plasma. There has been significant number of theoretical and experimental efforts to understand the electron distribution following ionization.⁵⁻⁷ For the case of a Li plasma, there is a conjecture that gain is enhanced because of a two temperature plasma.^{2,3,8} However, modeling places limits on the effectiveness of the cold component.⁹ Ionization-induced refraction can limit the lasing length.¹⁰⁻¹² The use of large focal spots allows for reasonable plasma lengths at the cost of lower intensity and longer wavelength x-ray lasing.¹⁰ In addition to work associated with heating and refraction, there has been modeling to show the benefit of the removal of ground-state electrons during lasing¹³ and having the initial state having a Rydberg electron.¹⁴ One variation of the field-ionization scheme has been very successful by using circularly polarized light. In this case, one has hot electrons following ionization and the upper-laser state is collisionally populated by these electrons. Using a Xe gas cell, an impressive $gL \approx 11$ was obtain at 418 Å.¹⁵ A different approach to x-ray lasing with USP lasers uses x-ray photoionization. An ultrashort pulse of incoherent x rays is produced, by heating a high-Z material, which inner-shell photoionizes a low-Z element. A rapid rise time of the incoherent x rays is critical for large gain coefficients. Short wavelength x-ray lasers are possible using existing USP lasers. For example, we calculate $gL \approx 10$ in C at 45 Å using a 30 fsec USP driving laser with an energy of 1 J.¹⁶

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16. For details on this approach see presentation at this conference by S. J. Moon and D. C. Eder.